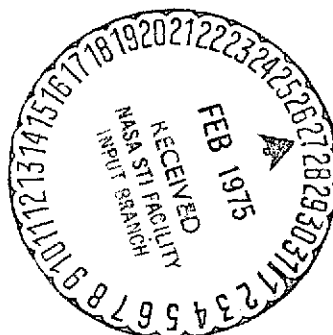


SOVIET AUTOMATIC INTERPLANETARY STATIONS
INVESTIGATE MARS

S.S. Sokolov

(NASA-TT-F-16152)	SOVIET AUTOMATIC	N75-17272
INTERPLANETARY STATIONS INVESTIGATE MARS		
(Scientific Translation Service)	32 p HC	
\$3.75	CSCL 22C	Unclas
		G3/91 09685

Translation of: "Sovetskiye
Avtomaticheskiye Mazhplanetnyye
Stantsii Issleduyut Mars", Vest-
nik Akademii Nauk SSSR, No. 10,
Oct. 1974, pp. 21 - 38.



1. Report No. NASA TT F-16,152		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Soviet Automatic Interplanetary Stations Investigate Mars				5. Report Date February, 1975	
				6. Performing Organization Code	
7. Author(s) S.S. Sokolov				8. Performing Organization Report No.	
				10. Work Unit No.	
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108				11. Contract or Grant No. NASW-2483	
				13. Type of Report and Period Covered Translation	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes Translation of: "Sovetskiye Avtomaticheskkiye Mazhplanetnyye Stantsii Issleduyut Mars", Vestnik Akademii Nauk SSSR, No. 10, Oct. 1974, pp. 21 - 38.					
16. Abstract All aspects of Soviet experiments with automatic martian stations, the Mars-2, Mars-3, ..., Mars-7 planetary probes, are discussed. The ballistic peculiarities of each flight are con- sidered, and the respective design specifics of each probe are reviewed. The separate systems of equipment described are: the system of thermal control of the probe interior, the radio- phototelemetric complex, the attitude system and its control, the system of autonomous control, the power supply system, the system of overall automatics, and the system of engines to pro- duce correcting and braking pulses. Details are discussed of the descent of planetary probes to the Mars surface, and the ground command-measurement complex for reception and processing of the telemetric and phototelevision information, for measure- of motion parameters, and for organization of control of space- craft in flight. Finally, the scientific instrumentation of the probe is also discussed, and preliminary results presented.					
17. Key Words (Selected by Author(s))				18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 32	
22. Price					

SOVIET AUTOMATIC INTERPLANETARY STATIONS INVESTIGATE MARS

S.S. Sokolov

Soviet practical astronautics has repeatedly demonstrated the wide range of possibilities for automatic interplanetary stations which investigate directly the Moon, the planets, near-lunar, near-planetary, and cosmic space, and which transmit reliable information from these bodies. Soviet automatic stations have contributed greatly to the study of Venus, whose atmospheric temperature at the landing site was 500°C, with a pressure of about 90 atmospheres. The self-propelled devices Lunokhod-1 and Lunokhod-2 operated many months under severe conditions of the lunar day and night, when the variation in the surface temperature of our natural satellite reached 300°C. This demonstrates the correctness of using automatic means to study space, and also demonstrates the operational reliability of these means. /21*

The development of these means has led to their "specialization", to the appearance of different types of stations: transit stations, artificial satellites, stationary landing devices, mobile landing devices, recoverable stations, etc. This in turn has allowed the formation of station complexes, or in other words, the joint and simultaneous use of two or more stations of either the same or different type. This has significantly extended the potential capabilities of space systems.

* Numbers in the margin indicate pagination of original foreign text.

Automatic systems have become the primary means for studying the planets of the solar system.

The experiment performed in 1971 by the Soviet automatic interplanetary stations (AIS) Mars-2 and Mars-3 was an important event in world science and technology. In the course of this experiment, the first soft landing in history on the surface of Mars was made by the descent capsule of the Mars-3 station. Also, Soviet artificial satellites of Mars were created, and a pennant bearing the Soviet National Emblem was delivered to the surface.

It is reasonable to investigate Mars from an orbiting satellite, because the planet is surrounded by an atmosphere which, in the absence of dust storms, is sufficiently "transparent" to allow observations of the Martian surface in different wave bands, including the optical. Prolonged observations of this type allow one to study large areas of the planetary surface, and to follow the changes which occur under the influence of so-called seasonal phenomena. An artificial satellite of Mars, appropriately equipped, is in fact a scientific laboratory extended into space. /22

Complex studies of Mars and near-Martian space were carried out in 1971 by two artificial satellites in very different orbits.

The study of Mars took on a new quality in 1973-1974, when four Soviet AIS — Mars-4, Mars-5, Mars-6 and Mars-7 — practically simultaneously reached the neighborhood of the planet, having completed an important stage of a multi-month space experiment.

The station Mars-4 photographed Mars from a flyby trajectory. An artificial satellite of Mars, the station Mars-5,

transmitted to Earth new information about the planet and the space surrounding it. High-quality photographs, including color photographs, of the Martian surface were obtained from the orbiting satellite. The descent capsule of the Mars-6 station landed on the planet, having first transmitted to Earth data on the Martian atmosphere which were obtained during the descent. The AIS Mars-6 and Mars-7 studied space from a heliocentric orbit.

In accordance with the Soviet program for the investigation of outer space and the planets of the solar system, these automatic stations were launched in July-August 1973. All stations were placed on a flight trajectory to the planet from an intermediate earth orbit. The injection into interplanetary orbit and the subsequent flight up to the approach to Mars were identical for all four stations. The required guidance accuracy was provided by trajectory corrections.

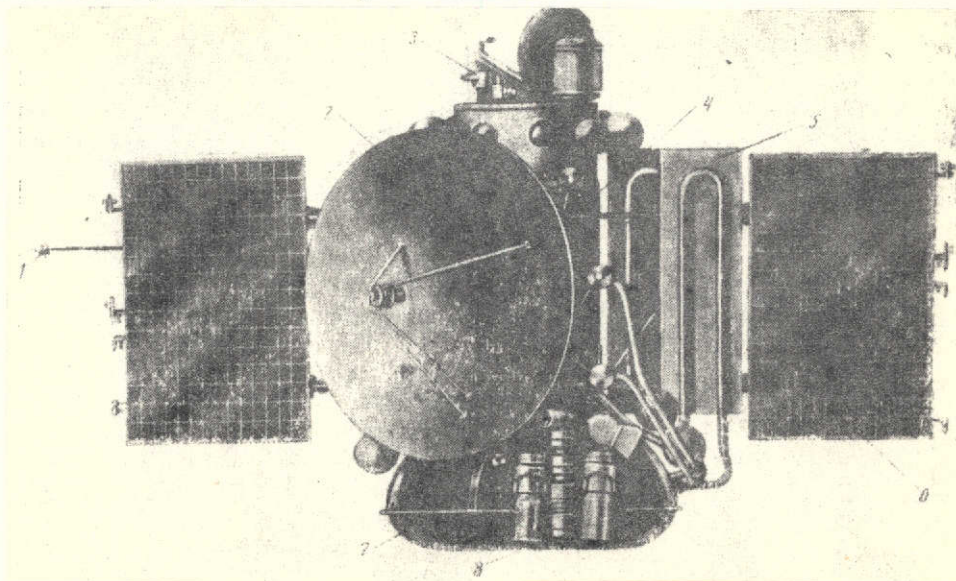


Figure 1.

General view of the Mars-5 station.

1) magnetometer; 2) highly directional parabolic antenna; 3) scientific apparatus; 4) semidirectional antennas; 5) radiators of the heat control system; 6) solar battery panel; 7) instrument compartment; 8) optical-electric devices for the attitude control system.

1 The main goal of the experiment was to continue and extend
2 the studies begun by Mars-2 and Mars-3 of the planet, the space
3 surrounding it, and also the characteristics of the interplane-
4 tary medium. The program provided for scientific measurements
5 from an orbiting satellite of Mars, from a flyby trajectory, and
also from descent capsules.

Ballistic features of the flight. The flight plan of the
AIS Mars-4, 5, 6, and 7 differed from the flight plan of Mars-2
and 3.

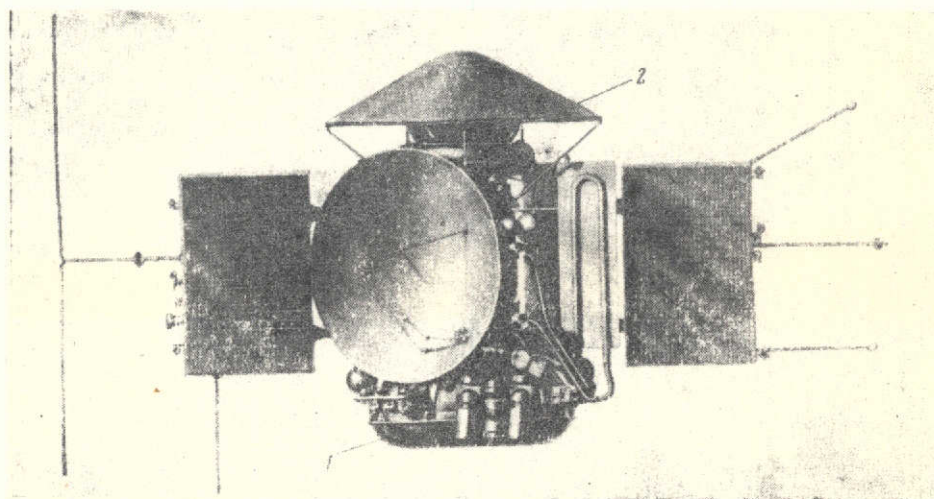


Figure 2.

General view of the Mars-6 station.
1) orbital compartment; 2) descent capsule.

The speed which must be imparted to a space vehicle in order
that it reach Mars and, correspondingly, the useful weight placed
onto the interplanetary trajectory vary as a function of the
start time. Usually the launch of space vehicles to Mars is
timed to coincide with the time of its opposition, which recurs
approximately every 780 mean solar days. Mars is closest to
Earth during periods of closest opposition (once in 15-17 years),
and "launch windows", the periods most favorable for flights to
the planet, occur in these years or close to them. Such was the
case in 1971, when the Soviet stations Mars-2 and Mars-3, and

also the American Mariner-9, started toward Mars.

The relative position of Earth and Mars in 1973 required that the flight speed of a station be higher than in 1971. Therefore the useful load was less when the same rocket-carrier was used. This explains the change in flight plans.

The AIS Mars-3 simultaneously solved two problems: delivery of a descent capsule to the planet and the creation of an artificial satellite of Mars. Accordingly, it consisted of two structurally independent parts: the descent capsule and an orbital compartment. Several hours before arrival at the planet the descent capsule was separated and transferred to a trajectory which insured landing in the preassigned region, while a braking pulse was applied to the orbital compartment at the moment of its closest approach with the planet, transferring it into an orbit around Mars.

For the AIS launched toward Mars in 1973 it was necessary to /24 adopt a so called double-start flight plan. According to this plan the problems of delivering the descent capsule and creating an artificial satellite of Mars were given to stations of different types. Stations of one type were intended for insertion into orbit around Mars and did not carry a descent capsule. In its place scientific instruments were placed on board for the study of the planet and the space around it from a satellite orbit. Also included was a reserve required to transfer stations to this orbit and for any necessary corrections in the orbit. The purpose of stations of the other type was to deliver a descent capsule to Mars (weight economy was achieved because there was no braking of the orbital compartment, which caused a decrease in the fuel supplies on board the station). Along with this a complex of scientific instruments was placed on these stations; the instruments were mainly for various investigations of inter-

planetary space.

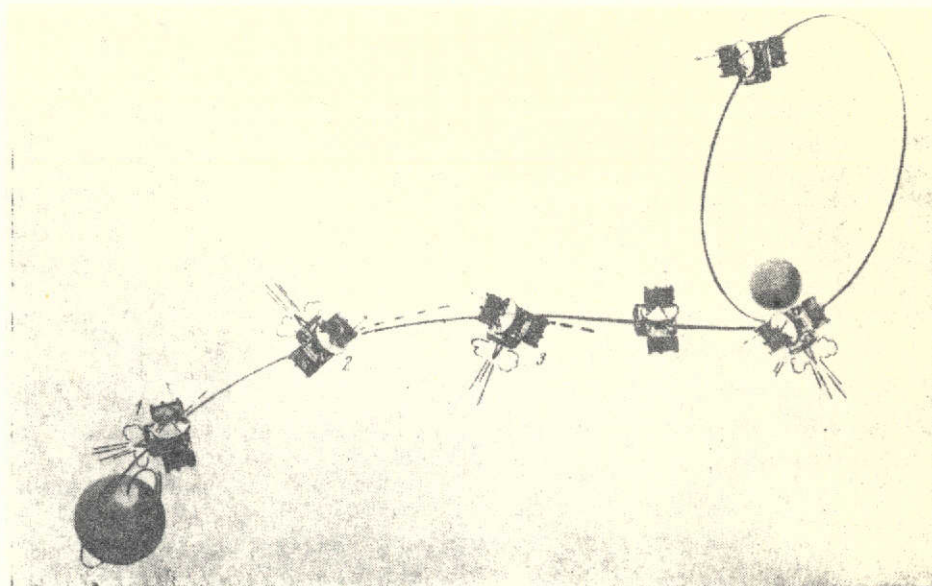


Figure 3.

Transit scheme for the Mars-5 station.

- 1) first correction; 2) second correction; 3) third correction;
- 4) braking of the orbital compartment.

Approximately two days before arrival each station entered within range of Mars and experienced attraction mainly from this source during the subsequent evolution of the mission. At a particular time before the closest approach with the planet the position of the AIS with respect to Mars was measured by means of a special optico-electronic device set up on board each station. The results of the measurements were processed by an on board computer, which calculated the parameters of the last correction and controlled its execution.

The subsequent stages of the flight of the stations were different. Mars-4 and Mars-5 moved along a hyperbolic approach trajectory toward the planet. In the region of the pericenter the motor imparted the required braking pulse to Mars-5, and after completion of the preassigned maneuvers the station went into orbit as an artificial satellite of Mars. While carrying

out investigation and photography from a flyby trajectory Mars-4 continued its flight along a heliocentric orbit without transferring to an areocentric orbit, because of a breakdown in the operation of one of the on-board systems. Descent capsules were separated from Mars-6 and Mars-7 after the execution of the final correction; the stations themselves continued their flight past Mars.

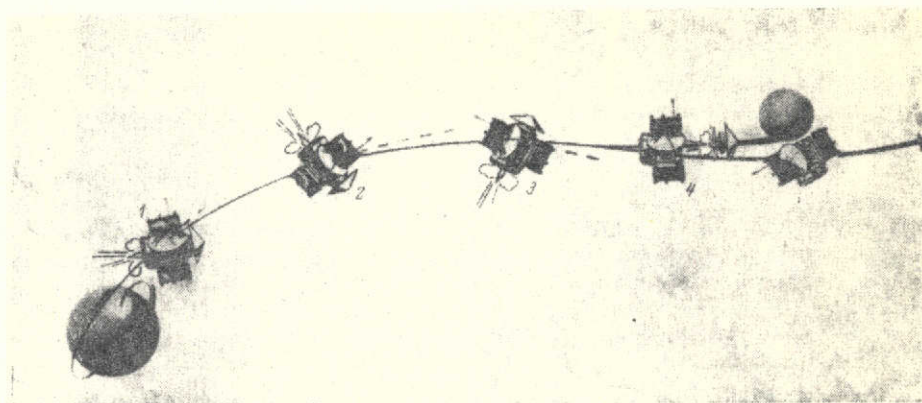


Figure 4.

Transit scheme for the Mars-6 station.

- 1) first correction; 2) second correction; 3) third correction;
- 4) separation of the descent capsule and its injection onto a descent trajectory.

The separated descent capsule from Mars-6 received an impulse from its motor, placing it on an impact trajectory which ensured landing in the preassigned region of Mars. Approximately 3.5 hours after separation from the orbital compartment the descent capsule entered the atmosphere of the planet, underwent aerodynamic braking, and landed. The descent capsule of the Mars-7 station was not placed on an impact trajectory.

We see that in comparison with a single-start flight plan the double-start plan is more complicated, but it enabled us not only to deliver a large useful weight to Mars, but also to specialize the scientific apparatus in accordance with the problems posed.

Construction of the stations. Mars-4 and Mars-5 are structurally similar, being orbital compartments in which the systems and assemblies guaranteeing operation of the stations on all stages of the flight are located. The instrument section, the power plant, solar panels, a parabolic highly directional antenna, omnidirectional antennas, and radiators for the cooling and heating circuits of the system which maintains the thermal regime are placed here. The block of fuel tanks for the power plant constitutes the main structural element, to which the assemblies are fixed. The scientific apparatus is set up in the upper part of the block of tanks. On the stations Mars-6, 7, in contrast to Mars-4, 5, the scientific apparatus is placed on a conical connecting member, which joins the instrument compartment and the block of tanks. The descent capsule is placed on the upper part of the block.

The descent capsule contains an automatic Martian station (approximately spherical in shape), an aerodynamic shield, a container with a parachute-rocket system, consisting of a parachute and soft-landing motor, and also a connective frame with systems which control the motion of the capsule during its separation from the orbital compartment, and which control its transfer from a flyby to an impact trajectory. After the change in trajectory this frame is separated from the descent capsule. /26

The aerodynamic shield has the form of a blunt cone, which ensures the necessary braking in the Martian atmosphere. The front side of the shield is covered with a heatproof material, which protects its metallic body from the action of high-temperature during aerodynamic braking. The automatic Martian station and the parachute-motor soft-landing system is placed at the base of the shield, protected from the effect of dynamic pressure and the high temperature of the on-rushing current. The Martian station is equipped with a special shock-absorber system which

absorbs the energy arising on contact with the surface of the planet.

The station also includes devices for placing it in an upright position after landing and for placing the scientific measurement devices directly on the surface of the planet.

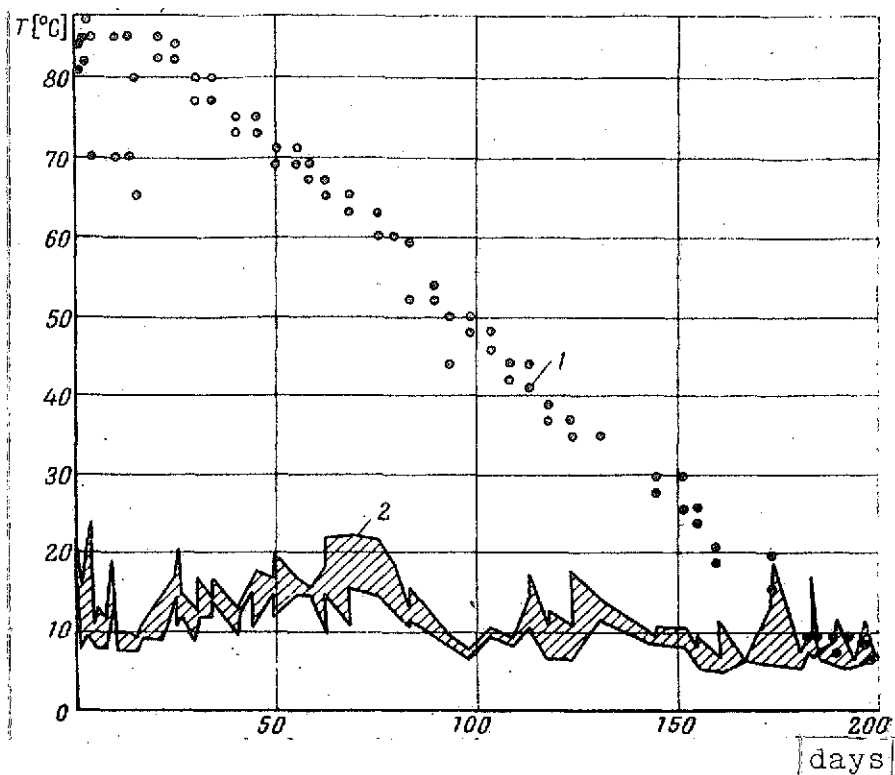


Figure 5.

Graph of the temperature variation for the gas inside the orbital compartment of the Mars-5 station.

1) surface temperature of the solar batteries; 2) gas temperature in the instrument compartment.

The principle features of the orbital compartment in the 1973 shots were determined by the problems of broadening the scientific experiments and placing the instruments of the orientation system in accordance with the kinematic characteristics of the flight trajectory.

Heat control system. Maintaining the station temperatures within specified limits is extremely important, because a devia-

tion from the allowed temperature can affect the electrical characteristics of the apparatus.

On the trajectory from Earth to Mars the automatic stations /27 were constantly subjected to the action of the heat flux of solar radiation, which decreases by a factor of two during the flight. As a result the temperature of the structural elements of the stations is changed; it decreases with increasing distance from the Sun. The temperature variation especially affects the solar batteries, instruments, and control members of the orientation system, which are placed outside the station.

The variation of the solar radiation flux and the internal heat release of the apparatus of the instrument compartments required that definite thermal conditions be maintained in the automatic stations. A compound system for heat control, consisting of active and passive media, was created for this purpose.

The active part is a two-circuit gas circulation system, including a heating circuit with a radiation radiator-heater removed to the outside and a cooling circuit with a radiation radiator-cooler. The heat carrier is the gas of the orbital compartment, circulating under the action of fans. Regulation of the heat control system is produced automatically by a device which consists of a control block, switching blocks, and a multi-position damper with a drive and sensing elements. The automatic system shifts the position of the damper upon receipt of a signal from the sensing element.

The passive media include vacuum-shield insulation, coverings with the necessary optical coefficients, and structural materials. The passive part, and also the active, regulates the thermal mode of the descent capsule, the solar batteries, the instruments.

of the orientation system, the control members, and a number of other pieces of equipment and structural elements of the stations.

Special vacuum installations equipped with solar simulators were developed to verify the thermal calculations. The analog of the automatic stations underwent a complete series of tests in these installations. The purpose of the tests was to check the capability of the heat control system to maintain the temperature regime within the given limits in all stages of station use.

The radio complex. The apparatus of the on-board radio-photo-telemetry complex of the orbital compartment includes an antenna feed system, automatic devices, a program-timing unit, instruments of the television and telemetry systems, and an apparatus for receiving information from the descent capsule. Measurements are made in all stages of the flight using the radio complex. The purpose of the measurements is to define the position of the station more precisely, and also to make the calculation of the parameters required for trajectory corrections more accurate.

The method for controlling the Mars stations is a combined command-programmed method, i.e., control is effected both from radio commands from Earth and by means of commands processed by the program-timing unit. In accordance with the program in this device, scientific and maintenance telemetry information is periodically recorded in the memory throughout the flight, with subsequent transmission of the data to Earth during periods of communication.

Varying-scale images of different portions of the surface of the planet were obtained and transmitted from an orbit of Mars using the photo-television system of the stations. This was done by two television devices with sevenfold overlap of the

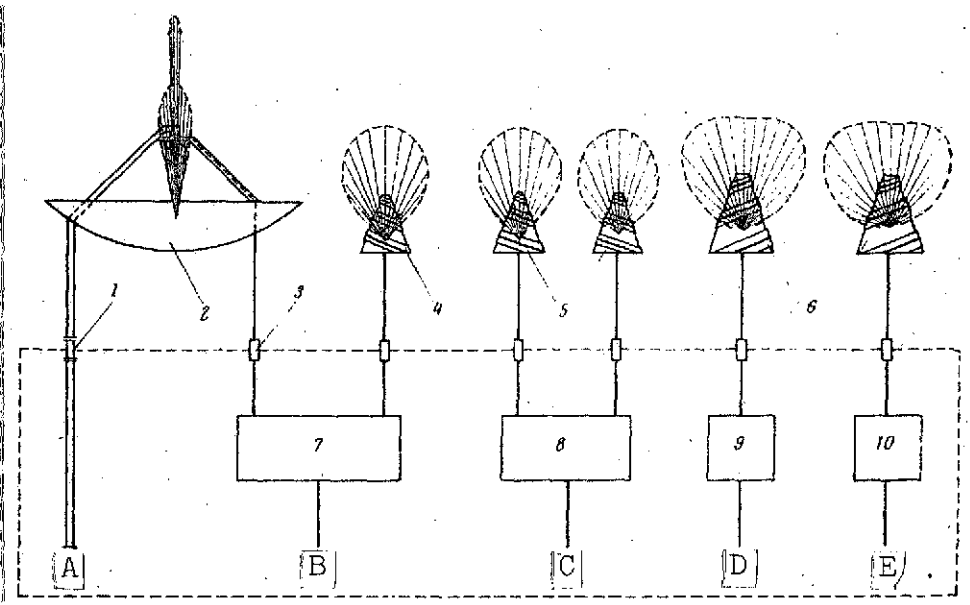


Figure 6.

Block diagram of the antenna feed system in the orbital compartment of the Mars-6 and Mars-7 stations.

1) sealed waveguide; 2) highly directional parabolic antenna; 3) high frequency plugs; 4) omnidirectional receiver-transmitter antenna; 5) omnidirectional antennas of the command radio link; 6) antennas for receiving information from the descent capsule; 7) antenna block for selection, switching, and indicating matching of the channel and the telemetry output; 8) filter block for the receiver channel of the command radio link; 9) filter for the first receiver channel for information from the descent capsule; 10) filter for the second receiver channel for information from the descent capsule; A) transmitter; B) receiver-transmitter for radio-photo-television system; C) receiver for the command radio link; D) receiver for information from the descent capsule (first channel); E) receiver for information from the descent capsule (second channel).

camera focal distances. Such a variation in the focal distances not only makes it possible to obtain photographs of the Martian surface with different resolutions, it also makes it possible to reference the locations of the frames with high resolution and maximum area coverage. The photographic results also provide a fix for the readings of the scientific instruments, tying them to specific regions of the surface. In some cases the pictures were taken through removable light filters, in order to obtain

color photographs of some portions of the surface. In addition, an image of a wide band of the area along the flight path was obtained using scanning optical-mechanical television devices.

After the descent capsule had entered the dense layers of atmosphere and its main radio link to the orbital compartment had begun to operate, a videotape recording was made of all information obtained during the parachute segment of the descent. The mode of relaying information from the descent capsule to Earth using the instruments of the orbital compartment, including the parabolic antenna, is favorable from a power point of view, because in this case there is no necessity of placing a large antenna on the descent capsule, which would require a special guidance system, powerful transmitters, etc.

The antenna feed system of each of the orbital compartments of Mars-4, 5, 6, and 7 consists of a highly directional parabolic antenna, three omnidirectional antennas, and two antennas for receiving information from the descent capsule.

Attitude control system. The attitude control system provides a basis for a coordinate system before carrying out a trajectory correction, orientation of the antennas of the on-board radio complex toward Earth with the necessary accuracy and maintenance of a definite orientation of the station with respect to the Sun. This is necessary for normal operation of the solar batteries and maintaining the preassigned thermal regime. The system includes optical-electronic devices for orientation towards the Sun, the Earth, and a star, gyroscopic pickups for the angular velocities of the station, and other apparatus.

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After the station is placed on its transit trajectory and is separated from the last stage of the rocket-carrier, the attitude control system damps out the angular velocities which

arise during separation, stops the irregular rotation of the station, and turns it to "seek" and "capture" the Sun, thereby bringing the station into the "constant solar orientation" mode. In this mode the solar panels are oriented toward the Sun, while the radiation patterns of the omnidirectional antennas are directed toward the Earth, ensuring the necessary conditions for radio communication between the AIS and the Earth.

To carry out trajectory corrections the station is placed in a mode of precise three-axis orientation: in addition to the orientation with respect to the sun, a search and capture of a star are performed. Thus, a basis for a system of coordinates is constructed, and the axes of the station are oriented in a definite way with respect to the Sun, the star, and the Earth.

As the station gets farther away from Earth the radiated power of the radio link decreases. To ensure high information content of the radio link at significant distances from Earth, the information is transmitted through the highly directional parabolic antenna, rather than through the omnidirectional antennas. The former has a narrow radiation pattern and a correspondingly large gain factor. For this the station is put into a mode of constant Sun-Earth orientation. In this mode solar panels are oriented towards the sun and the radiation pattern of the parabolic antenna is directed toward Earth.

Automatic control system. The purpose of this system is the control of the stations during the powered portions of the flight: insertion of the AIS into orbit around the Earth, control of the system in this orbit and during descent to the planet, and also the execution of powered maneuvers, including course corrections in flight. This system provides stabilization and programmed turns for the station in space; determines the times for switching the motor on and off for a given change in the

station velocity, and it determines the direction in space for the motor thrust. High accuracy in the automatic execution of the indicated functions is achieved by using precision apparatus and an on-board computer.

The control and navigation system solves key problems also during the concluding stage of the flight. The point is that the method of aerodynamic braking used for landing the descent capsules on the surface of Mars is applicable only for a relatively narrow band of planetary atmosphere entry angles for the station. If the entry angle is less than the acceptable value, a sharp variation occurs in the station trajectory, and it ricochets and leaves the neighborhood of Mars. If the entry angle is too large, the descent capsule will not have time to slow down to the given speed in the atmosphere, which has an extremely small density, and the descent mode will be disrupted. It is necessary to know with high accuracy the position of the planet in space relative to the station, in order to ensure a definite range of entry angles for the descent capsules and a precise insertion of the stations into the calculated orbits around Mars. This requires automatic measurements of the position of Mars in space directly from the station, which is close to the planet. /30

In order to perform such measurements the station is oriented with respect to the Sun and the star in such a way that the axis of the azimuthal optical-electronic automatic navigation device is directed toward the region of the calculated position of Mars. At a preassigned moment the magnitude and direction of the required correction impulse is determined from the magnitude of the deviation of the actual position of the planet and the calculated. This is done using the on-board computer. All the necessary calculations are performed, and the trajectory correction is carried out.

The power supply system uses the "generator buffer-battery" scheme. A semiconductor photoconverter solar battery is used as the generator. The solar battery charges the buffer battery and feeds the on board apparatus which operates between communication periods and it also charges the accumulator battery of the descent capsule. Because the illumination of the solar battery varies as it recedes from the Earth, its electrical circuit is constructed in such a way that the magnitude of the current and voltage are maintained within fixed limits as this happens.

An accumulator battery is used as the buffer battery for the orbital compartment. The high energy characteristics of the new accumulator battery have allowed the duration of the communication periods with the stations to be increased.

An accumulator battery is provided for feeding the on board apparatus of the descent capsule during its descent and its operation on the Martian surface. The battery is kept in the discharged state during the entire course of the flight. The battery of the descent capsule is charged a month before the approach to Mars.

System of general automatic equipment. This system is intended to control the on board systems of the station during the execution of the entire flight program, and it analyzes the signals necessary for coordination of the operation of the station systems. It does the logical processing of the signals and converts them into operating commands for control according to the preset program.

Let us dwell on some of the tasks performed by this system.

Part of the antennas of the radio complex, the panels of

solar batteries, and a number of structural elements were folded and fixed in this position prior to the launch of the station. According to a definite program, at a given time one of the blocks of the system of general automatic equipment opens up these devices using pyrotechnic devices.

Another of the tasks of this system is the connection of on-board receiver-transmitter radio devices to the antennas of the radio complex, depending on the mode of orientation of the station in space. While processing the information coming from the radio complex and the program-timing unit, the block of automatic unit switches on and off the apparatus necessary to carry out standard communications.

While the stations are in transit to the planet small meteorite particles can hit the lenses of the optical-electronic instruments of the orientation system and the phototelevision system. The lenses can also be soiled by gases formed during the operation of the motor. The lenses of a majority of the instruments are covered at definite times of the flight with special covers in order to shield them. Control of the drive mechanisms for the instrument covers is affected by a switching and automatic device unit, which logically processes the information coming from the various systems of the station.

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The most important automatic operations, which are responsible for the viability of the station, are duplicated by radio commands, which are transmitted when necessary from terrestrial control centers.

The motor assemblies for the Mars stations are intended to create correction and braking impulses, which provide trajectory corrections during the transit to Mars and braking for the stations during injection into the satellite orbit. The motor

assembly consists of a liquid rocket motor, a hydraulic system for feeding the fuel components to the motor, a pneumatic system for pressurization of the fuel tanks, and a control pressure system for controlling the motor assembly.

The multimode liquid rocket motor allows repeated restarts under conditions of vacuum and weightlessness. Commands to start and stop the motor, to change the thrust mode of the motor, and to generate stabilizing moments are issued by the station control system. Each motor and motor assembly undergoes the necessary bench tests in order to verify their operation and their conformance with the specified parameters.

The descent to the surface of the planet is one of the most important elements in the experiment to study Mars. The problem of organizing a landing in conditions of an extremely rarefied atmosphere is very complex. Analysis of the results of terrestrial observations on the atmosphere of the planet, as well as the results from the flight of the stations Mars-2, Mars-3, and Mariner-9 in 1971 indicated that the Martian atmosphere can introduce significant perturbations to the motion of the descent capsule. These perturbations are caused by strong winds, dust storms, different surface pressure in different regions, etc.

The entry of the descent capsule of the Mars-6 station into the atmosphere took place within the specified range of entry angles with a speed of about 6 km/sec. During the passive aerodynamic braking phase the stability of the descent capsule was provided by its external shape and alignment.

When the calculated value of the longitudinal load factor was attained, corresponding to the conditions for starting the operation of a special supersonic parachute system, a solid-fuel motor operated to free the drogue parachute. Then, with the

help of the drogue parachute, the main parachute was deployed in a reefed state. When the speed of the descent capsule had been reduced to approximately sonic speed the canopy of the main parachute was unreefed to complete filling, with practically simultaneous jettisoning of the aerodynamic fairing. After the removal of the aerodynamic fairing the radio altimeter was switched on; this provided a continuous value of the corresponding parameters to the analytic unit, and switched on the soft-landing motor in direct proximity of the surface of the planet.

The systems were actuated during the landing portion of the flight by commands from the program-timing unit.

The first measurements in the history of astronautics of the temperature and pressure of the Martian atmosphere were made during the parachute phase, and the chemical composition of the atmosphere was also determined. The results of these measurements are extremely important both for expansion of knowledge about the planet and for finding out the conditions under which future Martian stations must operate.

The ground command-measurement complex is intended for receiving, collecting, and processing telemetry and television information, measurements of motion parameters, and organization of the control for space vehicles in flight. The complex includes terrestrial measurement stations (TMP) on the territory of the Soviet Union, and also floating measurement stations (MP), the scientific research ships of the Academy of Sciences of the USSR, located in the waters of the Pacific and Atlantic Oceans.

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The TMP and MP along the flight path of the stations in turn receive and process information and measure trajectory parameters from the time of launch. The measurements begin with the entry of the apparatus into the region of radiovisibility of

a given measurement point and end when the subsequent point begins to receive the signal and process the information.

The remoteness of the measurement points from the Control Center imparts special significance to the organization of communication between them. Along with the usual means of communication an ever greater role is being allotted here to cosmic radio communication through the satellite Molniya-1 ("Lightning-1").

After launch of the stations Mars-4, 5, 6, and 7 from Earth orbit and after placing a number of structural elements into working position, the on-board radio transmitter and telemetry system were turned on. The first near-Earth communication phase had begun, and the state of the on board systems was determined from telemetry information, while the deviation of the actual trajectory from the calculated one was determined using trajectory measurements. Throughout the entire subsequent course of the flight information from the measurement points went to the coordination-computing center for processing and subsequent display in the Control Center, where a group of specialists for the various systems analyzed the functioning of the stations and their systems and developed control recommendations.

The center for long-range space communication is equipped with antennas and sensitive receivers, and provides for reception of signals from the space stations from distances of hundreds of millions of kilometers. The large gain of the antennas is due to their narrow radiation patterns. This in turn places severe demands not only on the orientation of the Mars stations during transmission of information through the highly-directional on-board antenna, but also on the prediction of the position of the station in space and the determination of its trajectory for the purpose of directing the narrow radiation pattern of the

terrestrial antenna to precisely that point in space where the station is located at any given moment.

The data necessary for this are processed by fast computers at the center for long-range space communication on the basis of the results of periodic trajectory measurements.

The difficult problem of extracting a useful signal, which has come from extreme distances and which carries information, from a background of various kinds of terrestrial and cosmic noise was successfully solved for the flight of the Mars stations. After detecting the signal and establishing communication with the station, the information was decoded by a terrestrial telemetry system. All of the information was directed into the computer for processing according to a special algorithm. A processing device transformed the phototelevision information into a video signal, which was sent to a video control device and used to obtain photographs. This apparatus is a complex system for amplifying, transforming, and processing signals. Using automatic devices it corrects and completely restores the original signal parameters.

In the center for long-range space communication there are also other systems, including an accurate timing system, which is necessary for referencing all the registered information to a precise time standard.

The terrestrial command-measurement complex is extremely complex and flexible, both with respect to its makeup and to the problems solved. Therefore, the interaction of its various elements, their precise, coordinated operation, is especially important. The increase in 1973 of the number of stations to four introduced not only quantitative, but also qualitative changes in the experiment. It increased the load on the equipment

at the terrestrial command-measurement point and increased the demands on the reliability of its systems.

Scientific equipment of the stations. Preliminary results.

The goal of the scientific studies of Mars is to obtain the clearest possible picture of the physical, chemical, areomorphological, and climatic conditions on this planet, and also to obtain information about the specific features of the interplanetary space surrounding the planet.

The topography of the surface was studied from an orbiting satellite of Mars using television devices and using the results from the measurements of the thickness of the fundamental atmospheric component, carbon dioxide. The quantity of this gas along the line of sight reflects the shape of the relief. Moisture estimates were made from this same orbit from the quantity of water vapor in the atmosphere, and the surface temperature of the planet was determined from infrared radiation.

The scientific instruments of the Mars-4 and Mars-5 stations were intended mainly to study a number of important characteristics of the planetary surface and the space near the planet from an orbiting satellite of Mars and from a flyby trajectory. The scientific instruments of the descent capsules on the Mars-6, 7 stations were intended mainly to study the characteristics of the space around the planet during descent, the physical and chemical parameters of the atmosphere and some of the surface parameters of Mars.

The flights to Mars of the Soviet stations Mars-2 and 3 and of a number of American space vehicles has already given much important information about the planet and the surrounding space. At the present time there are data on the topography of Mars, preliminary data on the soil properties of the surface layer, on

the surface temperature distribution and its variations, etc.

Continuation of the study of the topography of Mars has great value, both in a purely scientific sense and for realization of the subsequent program of Martian study. The character of the topography is directly connected with the areological activity of the planet and with processes causing change in the surface. The further study of the water content in the atmosphere and on its surface is of interest. The temperature distribution and its variation as a function of illumination enable one to judge the characteristics of rocks. This is extremely important, because up to now it is not clear what causes the differences in reflecting capability of the so called Martian seas and continents.

The scientific studies carried out by the Mars-4, 5, 6, and 7 stations were varied and extensive. At the present time the resulting data are being interpreted and analyzed. However, some results can already be discussed.

The photographs of the surface of the planet are distinguished by their extremely high quality. Details with dimensions as low as to 100 m can be distinguished. This makes photography one of the best ways of studying a planet. Color pictures of a number of segments of the Martian surface have been obtained by using colored light filters and a superposition of negatives. The color pictures are also of high quality and are useful for areologic-morphological and photometric studies.

There are many craters in the photographed regions. In some cases winding lines of depressions, ledges, and grooves are superimposed on the crater relief. Age difference explains the difference in the degree of disintegration.

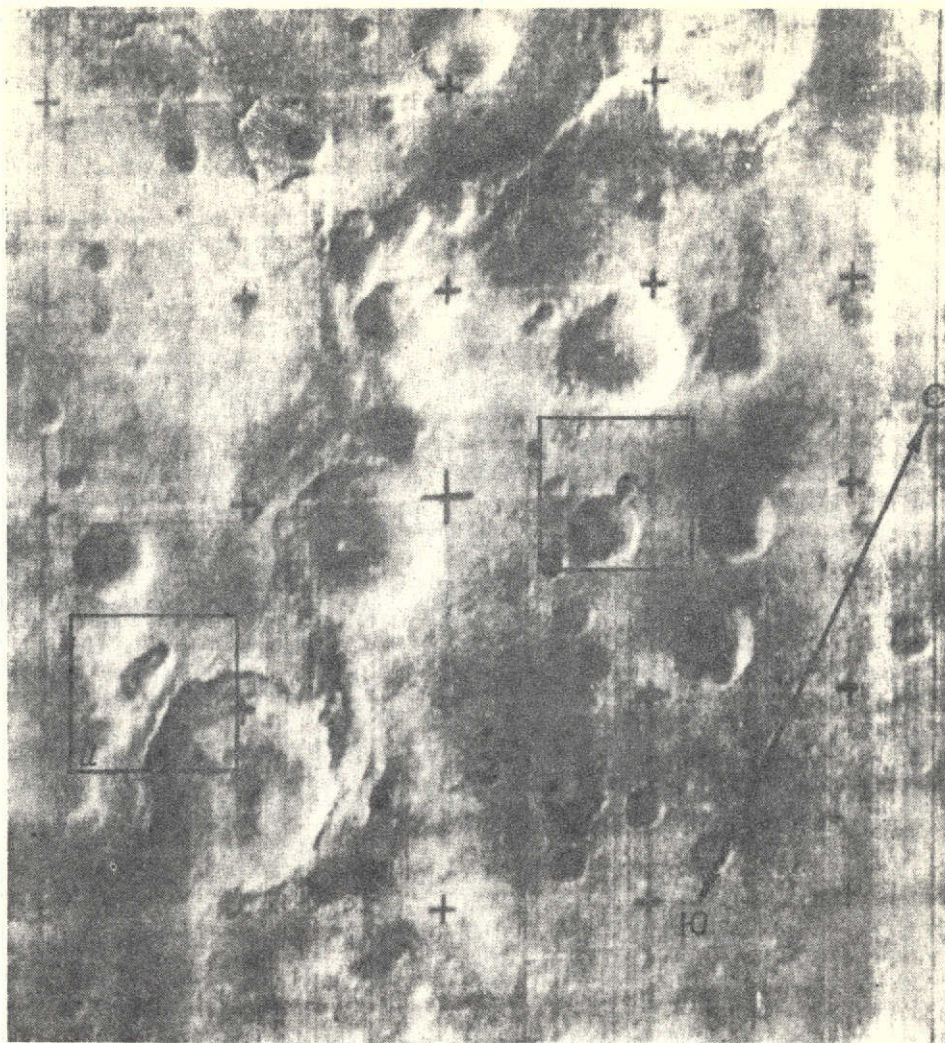


Figure 7.

Small-scale photograph of the Martian surface, obtained with the short focus television device of the Mars-5 station. Semidemo-lished craters are visible with diameter to 150 km. The main craters are connected by a channel of width 25-35 km. A narrower (5-7 km) winding channel "flows" into it from the northwest. The remaining part of the photographed surface is covered with numerous craters with regular shape and diameter from 20 to 70 km. All craters have slight elevations around the edges.

Simultaneously with the photography, a complex study of the surface and atmosphere was conducted using astrophysical methods. The instruments were coaxial with the axes of the television cameras. The instruments include ultraviolet photometers, a vi-

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Figure 8

Large-scale photograph of the Martian surface, obtained with the long focus television device of the Mars-5 station (the boundaries of this segment are outlined on Figure 7, square A). The photograph shows a sea-like region with part of a large crater, the bottom of which is speckled with numerous microformations of diameter about 1 km. Depth of the crater is crudely estimated to be approximately 1 km with respect to the west bank. An elongated eroded crater of smaller size (40x20 km) is located to the west of this crater. In the smaller crater, besides small craters from north to south, there are several embankments of considerable extent. In the northern part of this crater formation is a crater with a spherical bottom and diameter of about 10 km.

sible band photometer and a polarimeter, photometers for selected portions of the near infrared spectral region, a radiometer for the far infrared region, and a radio telescope. A spectrometer for measuring gamma radiation of the planet was included. This equipment allows one to analyze the radiation of the planet in a very broad spectral region, extending from 100 angstroms to 3 centimeters.

All instruments operated successfully during each pass of the Mars-5 station through the pericenter, and at precisely this moment the optical axes of the television devices and the astrophysical apparatus were oriented along the normal to the surface of the planet. During the time the measurements were taken, the altitude of the pericenter was about 1800 km. /35

The radiometer on the Mars-5 measured the surface temperature along the flight path. It was established that shortly after midday the temperature reaches 5-12 °C. However, already by six o'clock in the evening local time it drops to -20 and even -30 °C, and after 3-4 hours falls to -55 °C. Temperature variations of up to 5-8 degrees were observed along the flight path, which is explained by different absorption of solar rays by dark and light segments of the planet. (The minimum temperatures at the Martian poles can reach -120°C.)

Variations of altitude along the flight path of several kilometers were found using a special photometer for the carbon dioxide bands of the IR spectrum. Depressed and raised surface segments were also observed in the ultraviolet band. Thus, the study of the relief was checked by two independent methods. Brightness measurements in other wave bands indicated a small dust content in the Martian atmosphere in comparison with the stormy period of 1971. The study of the data obtained should, in particular, answer the question as to whether there is any /36

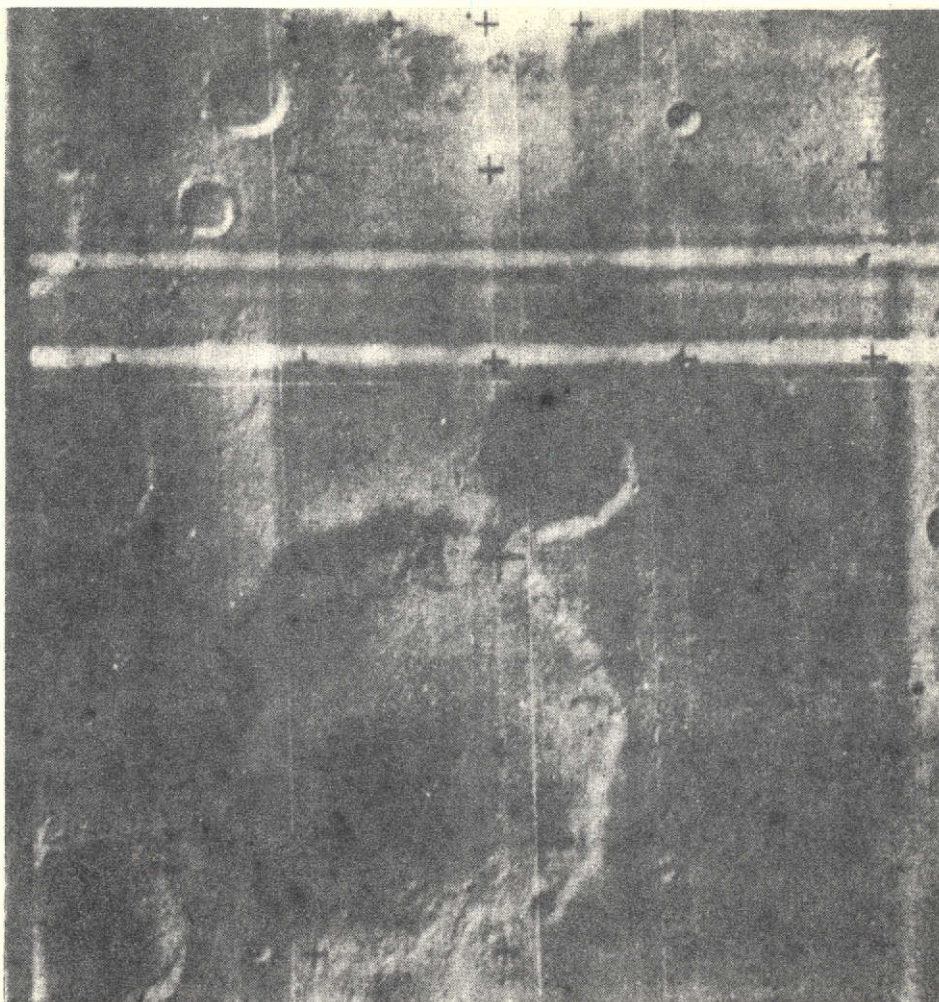


Figure 9.

Large-scale photograph of the Martian surface, obtained with the long focus television device of the Mars-5 station (the boundaries of this segment are outlined on Figure 7, square B). The photograph shows a crater of 45 km diameter and a "satellite" crater, of the order of 13 km. Both craters have shallow slopes with a speckling of small craters. The photograph clearly shows other craters of dimension from 2 to 15 km, with smoothed edges in the large craters and sharply rising edges in the small ones.

dependence between the color and the relief of Mars.

It is important to know that physical properties of the surface in order to construct the devices which are still to be landed on Mars. Measurements of this type were carried out by

two polarimeters set up on board the Mars-5 station jointly by Soviet and French scientists. It has turned out that the surface of the planet is very nonuniform. There are regions covered with a fine dust side-by-side with rocky areas. Further study in this direction should enable us to find out which terrestrial rocks are most similar to the Martian ones. Not long ago it was observed that different results of polarimeter measurements on the Moon are caused by variations in the lunar relief. Will such a connection be found on Mars, where in contrast to the Moon there is an atmosphere?

Measurements of the water vapor in the Martian atmosphere have indicated that its content exceeded the maximum quantity observed by the Mars-3 in 1972, and, by preliminary estimates, it reached 60 microns of precipitated water. It has been determined that along the flight path the amount of moisture varies by a factor of five.

Photometric profiles of the atmosphere at the limb of the planet have been obtained in a spectral region inaccessible to terrestrial observations, 2600-2800 angstroms. This was done using a two-channel ultraviolet photometer with high spatial resolution. These profiles resulted in the first observation of traces of ozone in the Martian atmosphere (the ozone data of the American probes Mariner-6, 7, and 9 referred to the solid surface of the polar cap). Also significant aerosol absorption was found even in the absence of dust storms. These data can be used to calculate the characteristics of the aerosol layer. Measurements of the ozone content of the atmosphere allow estimation of the concentration of atomic oxygen in the lower atmosphere and the rate of its vertical transfer out of the upper atmosphere. This is important for choosing a model to explain the stability of the carbon dioxide atmosphere existing on Mars. Results of measurements on the illuminated disk of the planet

can be used to study its relief.

Studies of the magnetic field in the near-Martian space carried out by the station Mars-5 have confirmed the conclusion made on the basis of similar studies by the Mars-2, 3 stations that a magnetic field on the order of 30 gammas exists near the planet (this is 7-10 times greater than the magnitude of the interplanetary unperturbed field carried by the solar wind). It is assumed that this magnetic field belongs to the planet itself, and Mars-5 favors this hypothesis.

Preliminary processing of the data from Mars-7 on the radiation intensity in the Lyman-alpha resonance line of atomic hydrogen has enabled one to estimate the profile of this line in interplanetary space and to determine in it two components, each of which makes an approximately equal contribution to the total radiation intensity. The information obtained makes it possible to calculate the speed, temperature, and density of interstellar hydrogen flowing into the solar system, and also to separate out the contribution of galactic radiation in the Lyman-alpha line. This experiment was performed jointly with French scientists.

The first direct measurement of the temperature of atomic hydrogen in the upper Martian atmosphere was made in a similar way from on board the Mars-5 station. Preliminary data processing indicates that this temperature is close to 350° K.

The descent capsule of the Mars-6 made measurements of the chemical composition of the Martian atmosphere using a radio-frequency mass spectrometer. Shortly after the main parachute opened, the analyzer was opened, and the Martian atmosphere was admitted into the device. From a preliminary analysis it can be concluded that argon makes up about one third of the atmosphere. This result is of fundamental significance for under-

standing the evolution of the Martian atmosphere.

Measurements of pressure and ambient temperature were also made on the descent capsule. The data on these characteristics in the region near the planet are being processed at the present time.

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We have already mentioned the participation of the French scientists in the polarimeter measurements and in measurements of the radiation intensity in the resonance line of hydrogen. An experiment in radio astronomy was also performed jointly, namely, measurements of radio emission by the sun in the one meter band. Reception of radiation simultaneously on Earth and on board an interplanetary station hundreds of millions of kilometers from Earth enables one to reconstruct a three-dimensional picture of the process of generating radio waves and to obtain data on the streams of charged particles responsible for these processes. Another problem was also solved in this experiment: the search for short bursts of radio emission, which may arise, as it is conjectured, in distant space from explosive-type phenomena in galactic nuclei, in supernova outbursts, and in other processes.

The Soviet Martian stations are complex automatic laboratories. The extensive information obtained by them deepens our knowledge of the universe and most of all our knowledge of one of the planets closest to the Earth in the solar system — Mars.

Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P. O. Box 5456, Santa Barbara, California, 93108.